

APPLICATION FOR UNITED STATES LETTERS PATENT

FOR

**IMAGE SENSOR WITH CHARGE RECYCLING**

Inventor: Hui Tian

Prepared by: Mendelsohn & Associates, P.C.  
1515 Market Street, Suite 715  
Philadelphia, Pennsylvania 19102  
(215) 557-6657  
Customer No. 22186

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## IMAGE SENSOR WITH CHARGE RECYCLING

### BACKGROUND OF THE INVENTION

#### Field of the Invention

5 The present invention relates to the field of integrated image sensor circuits.

#### Description of the Related Art

10 An integrated image sensor is used to convert light impinging on the sensor into electrical signals. An image sensor typically includes one or more (e.g., an array of) light-sensing photoelements such as photodiodes, phototransistors, or photodetectors, where electrical signals are generated via the well-known photoelectric effect. These signals may then be used, for example, to provide information about light intensity, color, or the optical image focused on the sensor. One common type of image sensor is a CMOS image sensor.

15 Fig. 1 shows a block diagram for a CMOS image sensor **100** implemented in a single integrated circuit or chip. Sensor **100** comprises a photoelement array **102**, a decoding/buffer area **104**, and control, processing, and input/output (I/O) circuitry **106**. Photoelement array **102** comprises an array of photoelements and associated circuitry such as switches and amplifiers. Each photoelement and its associated circuitry are collectively referred to as a pixel.

20 Sensor **100** can be switched into one of three operating modes: normal operation, standby, and power down. A typical operating cycle for sensor **100** in the normal operation mode has three steps: acquisition or integration, read-out, and reset. During the integration step, incident photons generate electrical charge that is accumulated within each photoelement in photoelement array **102** where the voltage across the photoelement is changed due to this charge accumulation. During the read-out step, the voltage is read out passively, i.e., without destroying the accumulated charge. During the reset step, the accumulated charge is drained from the photoelement thereby preparing it to receive photons during the next operating cycle. During the standby mode, if light is impinging on photoelement array **102**, the photoelements are converting light to current but the charge is not accumulated. During the standby mode, the associated circuitry within photoelement array **102** and the circuitry within blocks **104** and **106** used to operate the photoelements are typically powered up with only certain biases and control signals turned off so that the sensor can be quickly switched to the normal operation mode. During the power down mode, power is completely removed from the sensor.

30 Fig. 2 shows a schematic circuit diagram of part of integrated CMOS image sensor **100** of Fig. 1. Fig. 2 shows a pixel **202** of photoelement array **102** of Fig. 1, a voltage source  $V_{dd}$  **204**, a bias transistor **206**, and a read-out circuit **208**. Bias transistor **206** and read-out circuit **208** are typically implemented in blocks **104**

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and/or 106 of Fig. 1. Also shown are devices 210 that draw power from the same voltage source 204. Devices 210 may include but are not limited to on-chip circuitry, such as in blocks 104 and 106 of Fig. 1. Pixel 202 comprises a reset transistor 212, a photoelement 214, a source follower transistor 216, and a row select transistor 218.

During an integration step of the normal operation mode, reset transistor 212 and row select transistor 218 are turned off, and the voltage across photoelement 214 discharges in response to the incident light. After a predetermined integration time, transistor 218 is turned on to select the particular photoelement in the array and to initiate a read-out step of the normal operation mode. Read-out circuit 208 samples the gate voltage of transistor 216. During a reset step of the normal operation mode, reset transistor 212 is turned on, which drains the charge accumulated by photoelement 214 into  $V_{dd}$  204. This charge is thus irreversibly lost. During the standby mode, transistors 212 and 218 are turned off, but power is still applied to circuitry within sensor 100 (e.g., read-out circuit 208) and possibly devices 210. During the power down mode, power supply  $V_{dd}$  204 is disconnected from sensor 100.

Power consumption is important for portable and embedded imaging applications since the sensor is typically powered by a portable power source such as a battery. During the standby mode, the sensor consumes power due to off currents or other charge leakage through read-out circuit 208, devices 210, and/or other circuitry within sensor 100. This problem may become particularly serious for CMOS technology as it scales down to deep submicron levels due to increasingly higher doping densities, thinner oxide layers, and shorter channel lengths. Often, standby power consumption will limit battery life and restrict use of image sensors.

### SUMMARY OF THE INVENTION

Embodiments of the present invention are directed to a technique for reducing power consumption in integrated image sensors by which at least some of the charge generated by the sensor (e.g., during the sensor's normal operating mode) is used to power circuitry (e.g., during the sensor's standby mode), instead of drawing the entire current from a power source such as the external battery used to power the image sensor.

According to one embodiment, the present invention is a method for operating an integrated circuit having an image sensor with at least one photoelement comprising the steps of (a) generating charge by the photoelement and (b) applying at least a first portion of the charge generated by the photoelement to other circuitry to reduce consumption of power from a power supply.

According to another embodiment, the present invention is a circuit comprising (a) an image sensor having at least one photoelement implemented in an integrated circuit and (b) other circuitry, wherein the

photoelement generates charge that is applied to the other circuitry to reduce consumption of power from a power supply.

### BRIEF DESCRIPTION OF THE DRAWINGS

Other aspects, features, and advantages of the present invention will become more fully apparent from the following detailed description, the appended claims, and the accompanying drawings in which:

Fig. 1 shows a block diagram of an integrated CMOS image sensor of the prior art;

Fig. 2 shows a schematic circuit diagram of part of the integrated CMOS image sensor of Fig. 1;

Fig. 3 shows a schematic circuit diagram of part of an integrated CMOS image sensor according to one embodiment of the present invention; and

Fig. 4 shows a schematic circuit diagram of part of an integrated CMOS image sensor according to an alternative embodiment of the present invention.

### DETAILED DESCRIPTION

Reference herein to “one embodiment” or “an embodiment” means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one embodiment of the invention. The appearances of the phrase “in one embodiment” in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments. The description herein is largely based on a particular image sensor based on CMOS pixel sensor architecture. Those skilled in the art can appreciate that the description can be equally applied to other image sensors.

Fig. 3 shows a schematic circuit diagram of part of an integrated CMOS image sensor **300** according to one embodiment of the present invention. Fig. 3 shows a pixel **302** in the photoelement array of sensor **300**, a voltage source  $V_{dd}$  **304**, a bias transistor **306**, and a read-out circuit **308**. In a preferred embodiment, photoelement array **302** is a digital pixel sensor (DPS) array in which each pixel in array **302** includes an analog-to-digital converter. Also shown are devices **310** that draw power from the same voltage source **304**. Pixel **302** comprises a reset transistor **312**, a photoelement **314**, a source follower transistor **316**, and a row select transistor **318**. The sensor further comprises a capacitor **320**, switches **322-332**, and a control circuit **334**.

Initially, photoelement **314** is charged to a reset voltage level. During an integration step of the image sensor's normal operation mode, transistors **312** and **318** and switches **322**, **324**, **330**, and **332** are off. Switches **326** and **328** are on to allow for normal operation of devices **310** which are analogous to the previously described devices **210** of Fig. 2. As photoelement **314** is exposed to light, charge will accumulate and the

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voltage level of the gate of transistor 316 will drop. During a read-out step of the normal operation mode, transistor 318 is turned on to enable the gate voltage level of transistor 316 to be measured using read-out circuit 308.

According to one embodiment of the present invention, each reset step of the image sensor's normal operation mode has two phases, and the image sensor's standby mode also has two phases. During a first phase of each reset step, switches 322 and 332 are turned on, thereby transferring at least a portion of the charge from photoelement 314 to capacitor 320. After some duration (e.g., a few microseconds), switches 322 and 332 are turned back off and reset transistor 312 is turned on to implement a second phase of the reset step during which the rest of the charge accumulated in photoelement 314 is drained to  $V_{dd}$ .

During a first phase of the image sensor's standby mode, switches 326 and 328 are turned off and switches 324 and 330 are turned on substituting capacitor 320 for  $V_{dd}$  304 as the power source for devices 310. After running devices 310 on capacitor 320 for a period of time decided by control circuit 334, switches 324-330 are flipped back to the previous state, such that switches 326 and 328 are on and switches 324 and 330 are off, restoring  $V_{dd}$  304 as the power source to devices 310 for a second phase of the standby mode.

Image sensor 300 transitions from the first phase to the second phase of the reset step of the normal operation mode and from the first phase to the second phase of the standby mode based on control signals generated by control circuit 334. In one possible implementation, control circuit 334 is a closed-loop circuit that senses the voltage across capacitor 320. When this voltage rises above a specified first threshold value during the first phase of the reset step of the normal operation mode, control circuit 334 turns switches 322 and 332 off and switch 312 on, thus implementing the transition to the second phase of the reset step of the normal operation mode. Similarly, when the voltage across capacitor 320 drops below a specified second threshold value (possibly but not necessarily different from the first threshold value), control circuit 334 turns switches 324 and 330 off and switches 326 and 328 on, thus implementing the transition to the second phase of the standby mode.

In another possible implementation, control circuit 334 operates open loop using a timer comprising a counter and a clock input. The counter is reset at the onset of the reset step of the normal operation mode and again at the onset of the standby mode and begins to count the input clock pulses. When the count reaches a specified number for the current step/mode, control circuit 334 generates the appropriate control signals to transition to the second phase of the step/mode.

In yet another possible implementation, control circuit 334 senses current across devices 310. When this current falls below a specified threshold value for the current step/mode, control circuit 334 generates the appropriate control signals to transition to the second phase of the step/mode.

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Although devices **310** have been described in the context of Fig. 3 as having the same power source (e.g., **304**) as the image sensor, in general, devices **310** may comprise any off- or on-chip elements powered by either the image sensor's power supply or some other power sources. It should also be understood that capacitor **320** may be located off- or on-chip and may be replaced or supplemented by any other suitable storage device located off- or on-chip. Furthermore, capacitor **320** may comprise either a plurality of capacitors, for example one per pixel, or a single capacitor for the entire chip. In alternative embodiments, the capacitor or other such suitable storage device may be omitted if photoelement **314** directly connects to power-consuming circuitry when the image sensor generates photocurrent, as described further with respect to Fig. 4.

Fig. 4 shows a schematic circuit diagram of part of an integrated CMOS image sensor **400** according to one such embodiment of the present invention in which a storage device, such as capacitor **320** of Fig. 3, is not present. Fig. 4 shows a pixel **402**, a voltage source  $V_{dd}$  **404**, a bias transistor **406**, and a read-out circuit **408**. Also shown are devices **410** that draw power from the same voltage source **404**. Devices **410** are analogous to the previously described devices **310** of Fig. 3. Pixel **402** comprises a reset transistor **412**, a photoelement **414**, a source follower transistor **416**, and a row select transistor **418**. The sensor further comprises switches **420-424**.

During the standby mode, switches **422** and **424** are turned on and switch **420** is turned off. If light is impinging onto the image sensor during the standby mode, the photoelements generate photocurrent which is delivered to two input nodes of devices **410** with the current flowing from a positive node to a negative node. This current supplies at least a portion of the standby current consumed by devices **410** during the standby mode. To return to the normal operation mode, switch **420** is turned on and switches **422** and **424** are turned off.

In general, the present invention may be implemented for image sensors having one or more photoelements arranged in either a one- or two-dimensional pattern, such as an array of elements arranged in rows and columns. The individual photoelements within a given sensor array as well as associated circuitry may be the same or different. Although the present invention has been described in the context of CMOS technology for image sensors, it will be understood that the present invention can be implemented using other technologies, such as nMOS, pMOS, or other non-MOS technologies. Each photoelement may be based on any suitable light-sensitive device, such as, for example, a photodiode, a phototransistor, a photogate, photoconductor, a charge-coupled device, a charge-transfer device, or a charge-injection device. Similarly, as used in this specification, the term "light" refers to any suitable electromagnetic radiation in any wavelength and is not necessarily limited to visible light.

The use of figure reference labels in the claims is intended to identify one or more possible embodiments of the claimed subject matter in order to facilitate the interpretation of the claims. Such labeling

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is not to be construed as necessarily limiting the scope of those claims to the embodiments shown in the corresponding figures.

It will be further understood that various changes in the details, materials, and arrangements of the parts which have been described and illustrated in order to explain the nature of this invention may be made by those skilled in the art without departing from the principle and scope of the invention as expressed in the following claims. Although the steps in the following method claims, if any, are recited in a particular sequence with corresponding labeling, unless the claim recitations otherwise imply a particular sequence for implementing some or all of those steps, those steps are not necessarily intended to be limited to being implemented in that particular sequence.

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